NEW TIME SAVERS
IN HYDRAULICS AND EARTHWORK

BY

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LONGMANS, GREEN AND CO.

39 PATERNOSTER ROW, LONDON

FOURTH AVENUE & 30TH STREET, NEW YORK

BOMBAY, CALCUTTA, AND MADRAS

1914

INTRODUCTION

THESE time savers consist of the author's "Hydraulic Scales," from which the dimensions of pipes, drains and sewers can be easily and accurately ascertained, and his "Rapid Earthwork Calculation," from which the quantity of earthwork required in a bank or cut can be quickly calculated to, if necessary, the nearest inch of its depth,—strongly bound together into one convenient-sized manual.

C. E. H.

SCALES

FOR

ASCERTAINING THE DIMENSIONS OF
PIPES, DRAINS AND SEWERS

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PREFACE

THE accompanying Scales are taken from the Author's 'Water Supply and Drainage Systematised and Simplified,' in which work their construction is fully explained.

The dimensions, to the nearest inch, of pipes, of half-pipes, and of any design of drain or sewer in which a semicircle or circle can be inscribed, can be ascertained from them, adopting at will any desired coefficient.

Their issue in a handy setting will, it is hoped, recommend itself to the practical engineer.

C. E. H.

LONDON,
April 1914.

HYDRAULIC SCALES

SCALES HOW USED

THE use of the scales in ascertaining the diameters of pipes and of half-pipes is simple and direct. Thus, if S 'the slope in the water surface' or 'the hydraulic gradient' of a pipe $\left(\frac{H}{L}\right) = \frac{1}{1600}$ and the required discharge is 20 gallons per minute (galmins = G), the value of $\frac{L}{H}G^2$ will be $1600 \times 20^2 = 640{,}000$, and the required diameter in inches (d) of a clean pipe will from the small inset scale be 4 in.

For Kutter's $n = 0{\cdot}013$ it will be $4 + \frac{3}{4} = 4\frac{3}{4}$ in., and for an incrusted pipe it will be $4 + 1\frac{1}{4} = 5\frac{1}{4}$ in.

If, S being the same, the required discharge is 20 cubic ft. per second (cusecs = F) the value of $\frac{L}{H}F^2$ will be also 640,000, and the exact required diameter (d) of a clean pipe (Prof. Unwin's coefficients) will, from the main scale, be 38 in.; and, using the accompanying book-mark—

For Kutter's $n = 0{\cdot}013$ it will be $38 + 1 = 39$ in.
,, ,, $n = 0{\cdot}010$,, ,, ,, $38 - 3 = 35$ in.
,, an incrusted pipe ,, ,, ,, $38 + 6 = 44$ in.

and so on.

A 3

To ascertain the diameter of a half-pipe to give, with a slope in the water surface of 1 in 1600, a discharge of 20 cusecs we should have to take 4 times the value of $\frac{L}{H}F^2$ or $640{,}000 \times 4 = 2{,}560{,}000$, whence from the main scale d for a clean half-pipe = 49 in.

For Kutter's $n = 0{\cdot}013$, $d = 49 + 1 = 50$ in.
" " $n = 0{\cdot}010$, $d = 49 - 4 = 45$ in.

The scales can moreover be further used for ascertaining the dimensions of any type of drain or sewer the area of which can be ascertained in terms of the diameter of a circle or semicircle inscribed in the drain design.

Their use for this purpose is based on the following considerations.

For any drain, from well-known formulæ—

$$F = A\,v \quad . \quad . \quad . \quad . \quad \text{(i)}$$

when A is the water area in square feet, and
v is the velocity in feet per second;
also—

$$v = C\sqrt{R}\sqrt{S} \quad . \quad . \quad . \quad \text{(ii)}$$

where R the hydraulic mean depth or $\frac{\text{water area}}{\text{wetted perimeter}} = \frac{A}{P}$ and

$$C = \sqrt{\frac{2g}{m}} = \sqrt{\frac{64{\cdot}4}{m}}$$

m being a coefficient of flow, the value of which depends almost entirely on R and the character of the interior surface of the drain; therefore the value of $C\sqrt{R}$ for any given drain will, to all intents and purposes, be a constant and the velocity in the drain vary almost entirely with the slope of its water surface.

If now the hydraulic mean depth of the drain is the

same as the hydraulic mean radius of the inscribed circle or semicircle as is the case in a Type II. drain (Plate II.), the velocity in the drain for any slope of the water surface will be the same as it would be in a pipe or half-pipe with a similar interior surface and water slope.

The portion of the discharge flowing through the area of the drain section covered by the inscribed circle or semicircle can in such case be ascertained by a comparison of the area covered by the inscribed circle or semicircle with the area of the entire drain.

The coefficient so obtained may be designated 'the discharge reduction coefficient' and denoted by r', the value of d for the reduced discharge being ascertained from the scales by working out the value of $\frac{L}{H}(Fr')^2$.

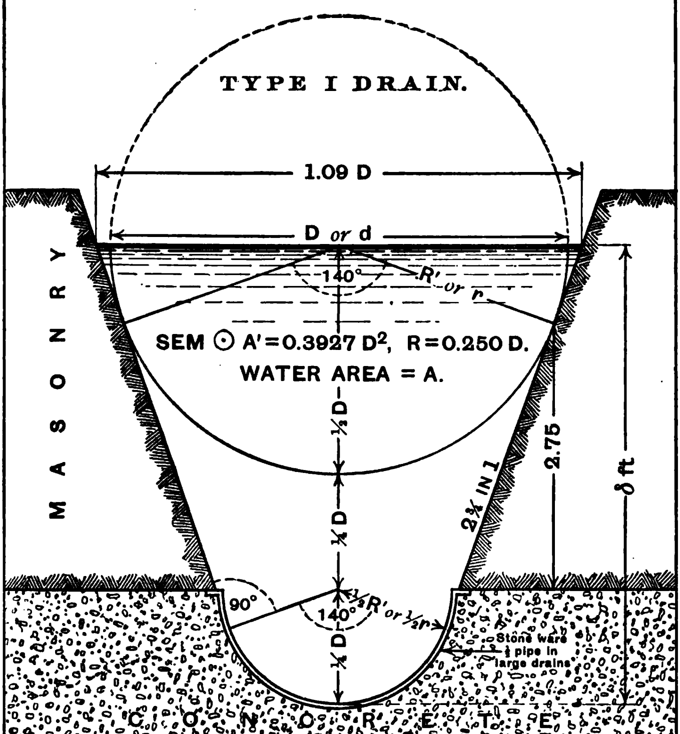
If however, as in a Type I. drain (Plate I.), the value of R for the drain exceeds the value of R for the inscribed circle or semicircle, as will generally be the case, the velocity in the drain will be greater than what would, under similar conditions, be the velocity in a pipe or half-pipe with the diameter of the inscribed circle or semicircle, and due allowance will have to be made for such increase in velocity.

Now, as shown above, the velocity in any drain or pipe will depend practically entirely on the value of $C\sqrt{R}$, ascertained from its hydraulic mean depth or hydraulic mean radius, which can for any slope in the water surface be very approximately calculated for Kutter's $n = 0{\cdot}013$ from the following formula—

$$C\sqrt{R} = \frac{182 \times R}{\sqrt{R} + 0{\cdot}56} \quad . \quad . \quad \text{(iii)}$$

With D (feet) = 1, the value of $C\sqrt{R}$ for a Type I. drain $= \frac{182 \times 0{\cdot}294}{0{\cdot}54 + 0{\cdot}56} = 48{\cdot}6$, and for the inscribed semicircle the value of $C\sqrt{R} = \frac{182 \times 0{\cdot}250}{0{\cdot}50 + 0{\cdot}56} = 43$; with D = 4 the respective

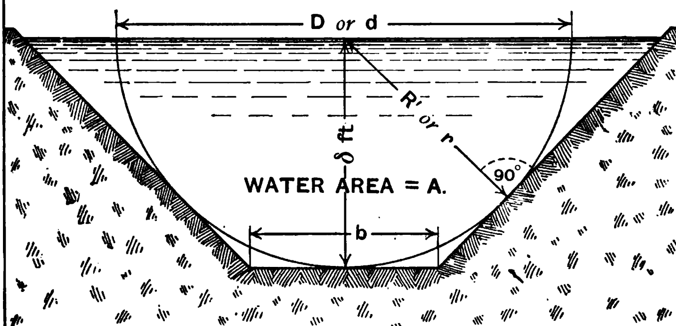
PLATE I.



DRAIN	SEWER
$A = 0.700\ D^2$, $P = 2.375\ D$,	$A = 1.089\ D^2$, $P = 3.946\ D$,
$R = 0.294\ D$, $r' = 0.500$.	$R = 0.276\ D$, $r' = 0.680$.

PLATE II.

TYPE II DRAIN.



SIDE SLOPES

0 TO 1	$A = 2\,\delta^2$	$b = 2\,\delta$	$r' = 0.786$
½ " 1	" $= 1.74\,\delta^2$	" $= 1.24\,\delta$	" $= 0.902$
1 " 1	" $= 1.83\,\delta^2$	" $= 0.83\,\delta$	" $= 0.859$
1½ " 1	" $= 2.11\,\delta^2$	" $= 0.61\,\delta$	" $= 0.745$
2 " 1	" $= 2.47\,\delta^2$	" $= 0.47\,\delta$	" $= 0.636$
2½ " 1	" $= 2.89\,\delta^2$	" $= 0.39\,\delta$	" $= 0.543$
3 " 1	" $= 3.33\,\delta^2$	" $= 0.33\,\delta$	" $= 0.472$

THE HYDRAULIC MEAN DEPTH

(R) always $= \frac{\delta}{2} = \frac{R'}{2}$

PLATE III.

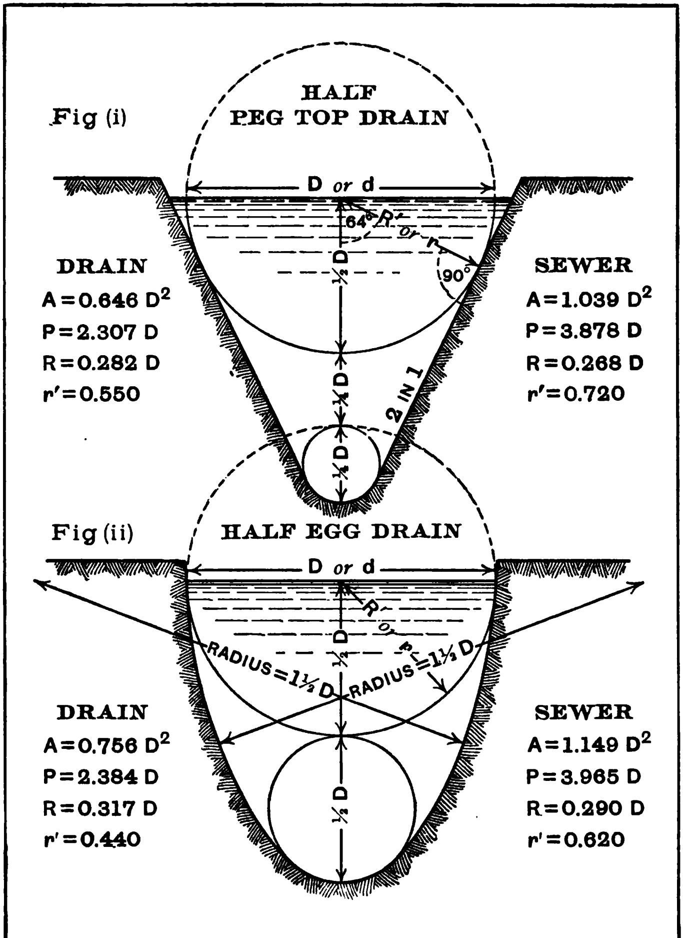
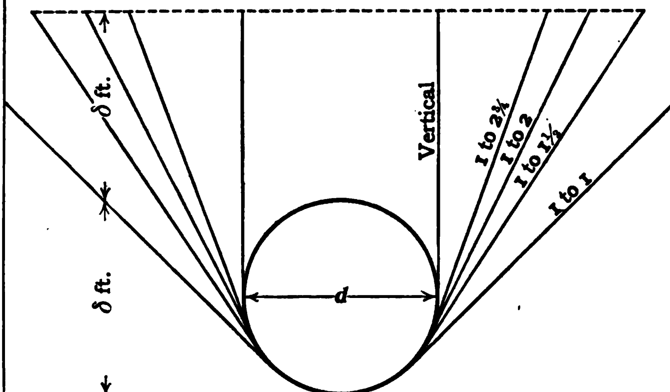


Fig (i)
HALF
PEG TOP DRAIN
D or d
64°
R or r
90°
½ D
¼ D
¼ D
2 IN 1
DRAIN
A=0.646 D²
P=2.307 D
R=0.282 D
r′=0.550
SEWER
A=1.039 D²
P=3.878 D
R=0.268 D
r′=0.720
Fig (ii)
HALF EGG DRAIN
D or d
R or r
½ D
RADIUS=1½ D
RADIUS=1½ D
½ D
DRAIN
A=0.756 D²
P=2.384 D
R=0.317 D
r′=0.440
SEWER
A=1.149 D²
P=3.965 D
R=0.290 D
r′=0.620

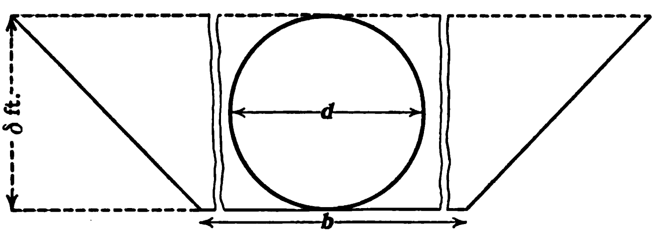
PLATE IV.

—TWO DRAIN TYPES—

—TYPE A.—FOR MASONRY DRAINS—



—TYPE B.—FOR DRAINS IN EARTH—



(For other particulars see Table 1.)

TABLE I

GIVING VALUES OF A, P, &c., FOR DRAIN TYPES ILLUSTRATED IN PLATE IV.

Type of drain	Values of							
	A		P		R		r	
SIDE SLOPES TYPE A	Full	Half	Full	Half	Full	Half	Full	Half
BASE: Vertical	$1·9\delta^2$	$0·90\delta^2$	$4·56\delta$	$2·56\delta$	$·417\delta$	$·352\delta$	·30	·65
BASE: 1 per $2\frac{3}{4}$	$2·8\delta^2$	$1·0\delta^2$	$4·75\delta$	$2·63\delta$	$·588\delta$	$·380\delta$	·15	·55
BASE: 1 ,, 2	$3·26\delta^2$	$1·1\delta^2$	$5·0\delta$	$2·81\delta$	$·652\delta$	$·392\delta$	·12	·50
BASE: 1 ,, $1\frac{1}{2}$	$3·75\delta^2$	$1·18\delta^2$	$5·25\delta$	$2·88\delta$	$·715\delta$	$·410\delta$	·095	·45
BASE: 1 ,, 1	$4·59\delta^2$	$1·34\delta^2$	$6·0\delta$	$3·13\delta$	$·765\delta$	$·428\delta$	·075	·40
SIDE SLOPES TYPE B								
$\frac{1}{2}$ to 1: $b = 2\delta$	$2·5\delta^2$		$4·2\delta$		$·60\delta$		·165	
$\frac{1}{2}$ to 1: $b = 3\delta$	$3·5\delta^2$		$5·2\delta$		$·67\delta$		·110	
$\frac{1}{2}$ to 1: $b = 4\delta$	$4·5\delta^2$		$6·2\delta$		$·72\delta$		·081	
$\frac{1}{2}$ to 1: $b = 5\delta$	$5·5\delta^2$		$7·2\delta$		$·76\delta$		·064	
$\frac{1}{2}$ to 1: $b = 6\delta$	$6·5\delta^2$		$8·2\delta$		$·80\delta$		·052	
1 to 1: $b = 2\delta$	$3\delta^2$		$4·8\delta$		$·63\delta$		·142	
1 to 1: $b = 3\delta$	$4\delta^2$		$5·8\delta$		$·69\delta$		·094	
1 to 1: $b = 4\delta$	$5\delta^2$		$6·8\delta$		$·73\delta$		·073	
1 to 1: $b = 5\delta$	$6\delta^2$		$7·8\delta$		$·76\delta$		·059	
1 to 1: $b = 6\delta$	$7\delta^2$		$8·8\delta$		$·80\delta$		·048	
2 to 1: $b = 2\delta$	$4\delta^2$		$6·2\delta$		$·64\delta$		·100	
2 to 1: $b = 3\delta$	$5\delta^2$		$7·2\delta$		$·70\delta$		·075	
2 to 1: $b = 4\delta$	$6\delta^2$		$8·2\delta$		$·74\delta$		·060	
2 to 1: $b = 5\delta$	$7\delta^2$		$9·2\delta$		$·77\delta$		·050	
2 to 1: $b = 6\delta$	$8\delta^2$		$10·2\delta$		$·80\delta$		·042	

values are: for drain $C\sqrt{R} = 130.5$, for semicircle $C\sqrt{R} = 116.6$; and with $D = 9$, $C\sqrt{R}$ for the drain $= 221$, and for the semicircle $C\sqrt{R} = 199$; whence the increased velocity in the drain will respectively be as 1·13 to 1, 1·12 to 1, and 1·11 to 1, or a mean of 112 to 100, and the value of r' will $= \frac{0.3927\ D^2}{0.700\ D^2} \times \frac{100}{112} = 0.50$.

Ascertained from a reduction coefficient so obtained the value of d for the inscribed semicircle in a Type I. drain will be slightly larger than it should be, as the values of d so obtained are based on the values of $\frac{L}{H}F^2$ calculated for $R = 0.250\,D$. An error on the right side.

Thus for an unplastered masonry or concrete drain of Type I. to give a discharge of 20 cusecs with a slope in the water surface of 1 in 1600 we have for a semicircle—

$$4\frac{L}{H}(Fr')^2 = 4 \times 1600 \times (20 \times 0.5)^2 = 640{,}000$$

whence from the main scale $d = 38 + 1 = 39$ in. Therefore $A = 0.700 \times 39^2 = 1064.7$ square in. or 7·4 square ft. Also $C\sqrt{R} = \frac{182 \times 0.96}{0.98 + 0.56} = 113.5$, whence with $S = 1$ in 1600 the velocity in the drain $= \frac{113.5}{\sqrt{1600}} = 2.84$ ft. per second.

The discharging capacity of the drain is thus $7.4 \times 2.84 = 21$ cusecs, instead of 20 cusecs.

The exact dimensions of the drain can be more nearly ascertained from the values of r' ascertained from an inscribed circle as shown in the full Type A drain section, side slopes 1 to $2\frac{3}{4}$, illustrated in Plate IV.

Thus to begin with, from Table I. (opposite page) $20 \times 0.15 = 3$ and $1600 \times 3^2 = 14{,}400$; therefore d for an unplastered drain $= 18 + 1$ or 19 in., whence half the depth of

the drain $\delta = 1$ ft. 7 in. and A the water area of a full drain, $2\cdot 8\delta^2, = 7\cdot 1$ square ft. Also as $C\sqrt{R} = \frac{182 \times 0\cdot 931}{0\cdot 96 + 0\cdot 56}$ $= 111\cdot 5$, $v = \frac{111\cdot 5}{40} = 2\cdot 79$ ft. per second, and F therefore = $7\cdot 1 \times 2\cdot 79 = 19\cdot 80$ cusecs.

For a drain in earth a Type II. drain would be usually adopted.

For a drain with side slopes of 1 to 1, $20 \times 0\cdot 859 =$ say 17 and $4 \times 1600 \times 17^2 = 1{,}849{,}600$, therefore for Kutter's $n = 0\cdot 025$, $d = 46 + 17 = 63$ in. $= 5\cdot 25$ ft., whence $A = 1\cdot 83 \times \left(\frac{5\cdot 25}{2}\right)^2 = 12\cdot 62$ square ft. and $R = \frac{5\cdot 25}{4} = 1\cdot 31$.

The values of $C\sqrt{R}$ for Kutter's $n = 0\cdot 025$ can be very approximately ascertained for any slope in the water surface from the formula—

$$C\sqrt{R} = \frac{117 \times R}{\sqrt{R} + 1\cdot 10} \quad . \quad . \quad \text{(iv)}$$

In the present case therefore—

$$C\sqrt{R} = \frac{117 \times 1\cdot 31}{1\cdot 15 + 1\cdot 10} = 68$$

and $v = \frac{68}{40} = 1\cdot 7$ ft. per second. F therefore $= 12\cdot 62 \times 1\cdot 7 = 21\cdot 45$ cusecs.

Occasionally a shallower drain than a Type II. drain may be advisable, and the dimensions of a Type B drain (Plate IV.) can be ascertained from the values of r' given in Table I.

Thus for a drain with $b = 4\delta$ and side slopes of 1 to 1, $F \times r' = 20 \times 0\cdot 073 =$ say $1\cdot 5$—

whence $\quad 1600 \times 1\cdot 5^2 = 3600$

and $\quad d$ for Kutter's $n = 0\cdot 025 = 14 + 6 = 20$ in.

Whence $$A = 5\delta^2 = 5 \times \left(\frac{20}{12}\right)^2 = 13{\cdot}8 \text{ square ft.}$$

and $$R = 0{\cdot}73\,\delta = 0{\cdot}73 \times 1{\cdot}67 = 1{\cdot}22$$

also $$C\sqrt{R} = \frac{117 \times 1{\cdot}22}{1{\cdot}1 + 1{\cdot}1} = \frac{142{\cdot}7}{2{\cdot}2} = 64{\cdot}8$$

therefore $$v = \frac{64{\cdot}8}{40} = 1{\cdot}62 \text{ ft. per second}$$

and $$F = Av = 13{\cdot}8 \times 1{\cdot}62 = 22{\cdot}36 \text{ cusecs.}$$

To ascertain the dimensions of an egg-shaped sewer (Plate III.) to discharge 20 cusecs with a slope in the water surface of 1 in 1600 we have $20 \times 0{\cdot}62 =$ say $12{\cdot}5$, and as for a circle $1600 \times 12{\cdot}5^2 = 250{,}000$, therefore d for an unplastered masonry or concrete sewer $= 31 + 1 = 32$ in.: whence $A = 1{\cdot}149 \times \left(\frac{32}{12}\right) = 8{\cdot}2$ square ft., and as $R = \frac{32}{12} \times 0{\cdot}290 = 0{\cdot}77$, $C\sqrt{R} = \frac{182 \times 0{\cdot}77}{0{\cdot}88 + 0{\cdot}56} = 97{\cdot}4$ and $v = \frac{97{\cdot}4}{40} = 2{\cdot}44$ ft. per second. F therefore $= 8{\cdot}2 \times 2{\cdot}44 = 20$ cusecs.

It will be seen from the above examples that the scales can be used for quickly and accurately ascertaining the dimensions of a number of useful types of drains and sewers to suit any required discharge and any slope in the water surface, adopting at will any desired coefficient. The velocity need not be worked out in each case except as an additional precaution to ensure that there is no mistake in the ascertained dimensions. It is, however, essential that there should be no great error in the ascertained values of $\frac{L}{H}G^2$ or $\frac{L}{H}F^2$. These can be checked from Table II. in the following manner:—

With $S = \frac{1}{1532}$ and $F = 13$ cusecs take and add from the horizontal column opposite required discharge $= 13$—

1000 times the figure in the vertical col.					1	=	169,000
100	,,	,,	,,	,,	5	=	84,500
10	,,	,,	,,	,,	3	=	5,070
1	,,	,,	,,	,,	2	=	338
and the value of 1532×13^2 will						=	258,908

With $F = 1{\cdot}3$ the value of $\frac{L}{H}F^2$ will obviously be 2589·08, and with $F = 130$ it will be 25,890,800.

With $F = 13{\cdot}5$ a mean may be taken between the ascertained values for $F = 13$ and $F = 14$.

TABLE II

Required Discharge	Square of Discharge Multiplied by								
	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	7	8	9
2	4	8	12	16	20	24	28	32	36
3	9	18	27	36	45	54	63	72	81
4	16	32	48	64	80	96	112	128	144
5	25	50	75	100	125	150	175	200	225
6	36	72	108	144	180	216	252	288	324
7	49	98	147	196	245	294	343	392	441
8	64	128	192	256	320	384	448	512	576
9	81	162	243	324	405	486	567	648	729
10	100	200	300	400	500	600	700	800	900
11	121	242	363	484	605	726	847	968	1089
12	144	288	432	576	720	864	1008	1152	1296
13	169	338	507	676	845	1014	1183	1352	1521
14	196	392	588	784	980	1176	1372	1568	1764
15	225	450	675	900	1125	1350	1575	1800	2025
16	256	512	768	1024	1280	1536	1792	2048	2304
17	289	578	867	1156	1445	1734	2023	2312	2601
18	324	648	972	1296	1620	1944	2268	2592	2916
19	361	722	1083	1444	1805	2166	2527	2888	3249
20	400	800	1200	1600	2000	2400	2800	3200	3600
21	441	882	1323	1764	2205	2646	3087	3528	3969
22	484	968	1452	1936	2420	2904	3388	3872	4356
23	529	1058	1587	2116	2645	3174	3703	4232	4761
24	576	1152	1728	2304	2880	3456	4032	4608	5184
25	625	1250	1875	2500	3125	3750	4375	5000	5625
Galmins or Cusecs	1	2	3	4	5	6	7	8	9

TABLE II (*cont.*)

Required Discharge	Square of Discharge Multiplied by								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
26	676	1352	2028	2704	3380	4056	4732	5408	6084
27	729	1458	2187	2916	3645	4374	5103	5832	6561
28	784	1568	2352	3136	3920	4704	5488	6272	7056
29	841	1682	2523	3364	4205	5046	5887	6728	7569
30	900	1800	2700	3600	4500	5400	6300	7200	8100
31	961	1922	2883	3844	4805	5766	6727	7688	8649
32	1024	2048	3072	4096	5120	6144	7168	8192	9216
33	1089	2178	3267	4356	5445	6534	7623	8712	9801
34	1156	2312	3468	4624	5780	6936	8092	9248	10404
35	1225	2450	3675	4900	6125	7350	8575	9800	11025
36	1296	2592	3888	5184	6480	7776	9072	10368	11664
37	1369	2738	4107	5476	6845	8214	9583	10952	12321
38	1444	2888	4332	5776	7220	8664	10108	11552	12996
39	1521	3042	4563	6084	7605	9126	10647	12168	13689
40	1600	3200	4800	6400	8000	9600	11200	12800	14400
41	1681	3362	5043	6724	8405	10086	11767	13448	15129
42	1764	3528	5292	7056	8820	10584	12348	14112	15876
43	1849	3698	5547	7396	9245	11094	12943	14792	16641
44	1936	3872	5808	7744	9680	11616	13552	15488	17424
45	2025	4050	6075	8100	10125	12150	14175	16200	18225
46	2116	4232	6348	8464	10580	12696	14812	16928	19044
47	2209	4418	6627	8836	11045	13254	15463	17672	19881
48	2304	4608	6912	9216	11520	13824	16128	18432	20736
49	2401	4802	7203	9604	12005	14406	16807	19208	21609
50	2500	5000	7500	10000	12500	15000	17500	20000	22500
Galmins or Cusecs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

TABLE II (*cont.*)

Required Discharge	Square of Discharge Multiplied by								
	1	2	3	4	5	6	7	8	9
51	2601	5202	7803	10404	13005	15606	18207	20808	23409
52	2704	5408	8112	10816	13520	16224	18928	21632	24336
53	2809	5618	8427	11236	14045	16854	19663	22472	25281
54	2916	5832	8748	11664	14580	17496	20412	23328	26244
55	3025	6050	9075	12100	15125	18150	21175	24200	27225
56	3136	6272	9408	12544	15680	18816	21952	25088	28224
57	3249	6498	9747	12996	16245	19494	22743	25992	29241
58	3364	6728	10092	13456	16820	20184	23548	26912	30276
59	3481	6962	10443	13924	17405	20886	24367	27848	31329
60	3600	7200	10800	14400	18000	21600	25200	28800	32400
61	3721	7442	11163	14884	18605	22326	26047	29768	33489
62	3844	7688	11532	15376	19220	23064	26908	30752	34596
63	3969	7938	11907	15876	19845	23814	27783	31752	35721
64	4096	8192	12288	16384	20480	24576	28672	32768	36864
65	4225	8450	12675	16900	21125	25350	29575	33800	38025
66	4356	8712	13068	17424	21780	26136	30492	34848	39204
67	4489	8978	13467	17956	22445	26934	31423	35912	40401
68	4624	9248	13872	18496	23120	27744	32368	36992	41616
69	4761	9522	14283	19044	23805	28566	33327	38088	42849
70	4900	9800	14700	19600	24500	29400	34300	39200	44100
71	5041	10082	15123	20164	25205	30246	35287	40328	45369
72	5184	10368	15552	20736	25920	31104	36288	41472	46656
73	5329	10658	15987	21316	26645	31974	37303	42632	47961
74	5476	10952	16428	21904	27380	32856	38332	43808	49284
75	5625	11250	16875	22500	28125	33750	39375	45000	50625
Galmins or Cusecs	1	2	3	4	5	6	7	8	9

TABLE II (*cont.*)

Required Discharge	Square of Discharge Multiplied by								
	1	2	3	4	5	6	7	8	9
76	5776	11552	17328	23104	28880	34656	40432	46208	51984
77	5929	11858	17787	23716	29645	35574	41503	47432	53361
78	6084	12168	18252	24336	30420	36504	42588	48672	54756
79	6241	12482	18723	24964	31205	37446	43687	49928	56169
80	6400	12800	19200	25600	32000	38400	44800	51200	57600
81	6561	13122	19683	26244	32805	39366	45927	52488	59049
82	6724	13448	20172	26896	33620	40344	47068	53792	60516
83	6889	13778	20667	27556	34445	41334	48223	55112	62001
84	7056	14112	21168	28224	35280	42336	49392	56448	63504
85	7225	14450	21675	28900	36125	43350	50575	57800	65025
86	7396	14792	22188	29584	36980	44376	51772	59168	66564
87	7569	15138	22707	30276	37845	45414	52983	60552	68121
88	7744	15488	23232	30976	38720	46464	54208	61952	69696
89	7921	15842	23763	31684	39605	47526	55447	63368	71289
90	8100	16200	24300	32400	40500	48600	56700	64800	72900
91	8281	16562	24843	33124	41405	49686	57967	66248	74529
92	8464	16928	25392	33856	42320	50784	59248	67712	76176
93	8649	17298	25947	34596	43245	51894	60543	69192	77841
94	8836	17672	26508	35344	44180	53016	61852	70688	79524
95	9025	18050	27075	36100	45125	54150	63175	72200	81225
96	9216	18432	27648	36864	46080	55296	64512	73728	82944
97	9409	18818	28227	37636	47045	56464	65863	75272	84681
98	9604	19208	28812	38416	48020	57624	67228	76832	86436
99	9801	19602	29403	39204	49005	58806	68607	78408	88209
100	10000	20000	30000	40000	50000	60000	70000	80000	90000
Galmins or Cusecs	1	2	3	4	5	6	7	8	9

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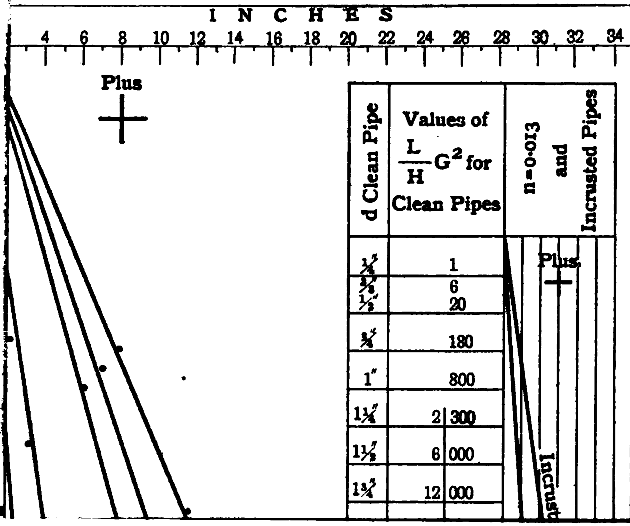
FOR ASCERTAINING THE DIMENSIONS OF PIPES



d Clean Pipe	Values of $\frac{L}{H}G^2$ for Clean Pipes	n=0·013 and Incrusted Pipes
¼″	1	
⅜″	6	
½″	20	
¾″	180	
1″	800	
1¼″	2 300	
1½″	6 000	
1¾″	12 000	

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RAPID EARTHWORK CALCULATION

BY

C. E. HOUSDEN

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WITH DIAGRAMS

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39, PATERNOSTER ROW, LONDON
FOURTH AVENUE & 30TH STREET, NEW YORK
BOMBAY, CALCUTTA, AND MADRAS
1914

PREFACE

This small work embodies improvements in earthwork calculation suggested by a careful reconsideration of the author's "Practical Earthwork Tables," these Tables, as well as their application, being considerably simplified yet left sufficiently full to allow of correct results being arrived at under all the conditions likely to be met with in actual practice.

With so many Tables already in existence for a similar purpose new ones may at first sight appear unnecessary and superfluous; actual trial will, however, prove that earthwork quantities can be from them ascertained, as within explained, more quickly and with less labour than in any other way.

C. E. H.

London,
July, 1914.

CONTENTS

RAPID EARTHWORK CALCULATION

CHAPTER I

INTRODUCTORY

THE usual procedure for ascertaining the amount of earthwork likely to be needed in an embankment or in a cutting is—

(*a*) First of all to prepare a longitudinal section along the centre line of the proposed bank or cut from levels taken at, as far as possible, regular intervals along this line, and also to prepare cross-sections at right angles to the centre line at the points at which the levels are taken; (*b*) to then determine from the plotted cross-sections the areas of embankment and cutting required at each such station; and (*c*) finally to calculate from the areas so obtained the contents of the bank or cut from the

prismoidal formula or from the mean areas of adjacent cross-sections.

The above procedure necessitates a good deal of work in the preparation of the cross-sections and also in the numerical calculations necessary before and after the areas of bank and cutting at each station can be and have been ascertained. The accompanying Tables and connected formulæ will be found to be of material assistance in the reduction of such work.

Where the ground at right angles to the centre line is level or has a uniform cross slope the preparation of any cross-sections is by their use rendered unnecessary.

Where the cross slopes at the selected points are not uniform the preparation of the cross-sections can be also generally avoided by the adoption of an average cross slope at each station, or is at any rate much simplified.

The Tables are, however, especially applicable to the rapid and direct calculation, by the system later on explained, of the cubic contents of long embankments. and cuttings carried over or through ground which rises and. falls to a considerable extent.

This method of ascertaining the contents of a bank or of a cut further allows of an easy check being kept on the progress of work when such bank comes to be thrown up or such cutting made, an additional advantage in its favour.

For rapidly ascertaining the relative cost of trial lines it will be found also most useful.

CHAPTER II

TABLES, HOW FRAMED

THE usual cross-sections of embankments and cuttings on level ground (area in square feet = A) are illustrated in Fig. (i.)—

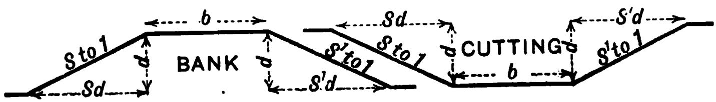


FIG. i.

where—

(b) is, in feet, the top width of a bank or the bed width of a cut;

(d) is, in feet, the height of a bank or the depth of a cut; and

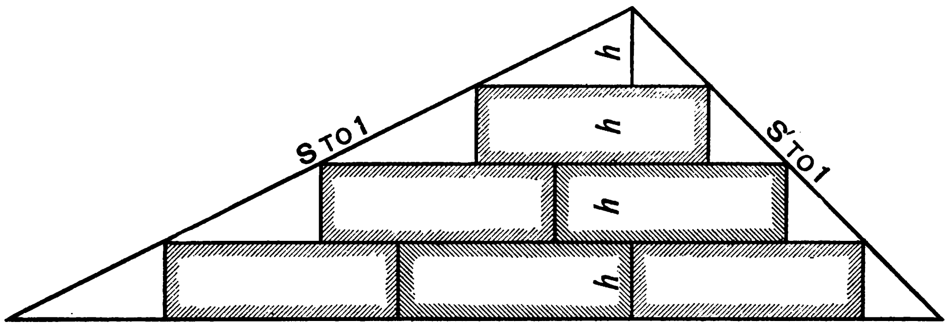
S, S′, are the horizontal values to 1 of the side slopes generally denoted as $\frac{1}{2}$ to 1, 1 to 1, 2 to 1, and so on.

If the central area $b \times d$ is eliminated the values of the remaining triangular end areas will depend directly on the values of S and S′.

Thus for any depth h the combined area of

PLATE I

DIAGRAM
SHEWING INCREASING AREAS
OF SIDE SLOPES



the two end areas will (see Plate I.) be equal to—

$$\tfrac{1}{2}h(\mathrm{S}h + \mathrm{S}'h) \text{ or } \tfrac{1}{2}h^2(\mathrm{S} + \mathrm{S}') \quad . \quad . \quad (\text{i.})$$

Their area for an additional depth h will be—

$$\tfrac{1}{2}h^2(\mathrm{S} + \mathrm{S}') + h^2(\mathrm{S} + \mathrm{S}') \quad . \quad . \quad . \quad (\text{ii.})$$

Equation (ii.) can, however, be written—

$$2h^2(\mathrm{S} + \mathrm{S}') - \tfrac{1}{2}h^2(\mathrm{S} + \mathrm{S}') \quad . \quad . \quad . \quad (\text{iii.})$$

hence the area (A^n) of an nth layer can be obtained from the equation—

$$\mathrm{A}^n = nh^2(\mathrm{S} + \mathrm{S}') - \tfrac{1}{2}h^2(\mathrm{S} + \mathrm{S}') \quad . \quad (\text{iv.})$$

The increase in area for each layer will from equation (ii.) obviously be—

$$\text{Difference} = h^2(\mathrm{S} + \mathrm{S}') \quad . \quad . \quad . \quad (\text{v.})$$

The Tables at the end of work, which can be easily extended, have been prepared from the above formulæ with $h = 1$ foot, and are applicable to banks or cuttings of a total height or depth of 30 feet, with side slopes varying from $\frac{1}{2}$ to 1 to 4 to 1 on both sides to $\frac{1}{2}$ to 1 on one side and $7\frac{1}{2}$ to 1 on the other one.

The combined area (A^1) of the end areas of a layer i inches deep immediately below a nth one foot layer can be further ascertained from the formula—

$$A^1 = \text{Difference} \times \frac{i}{12}\left\{n + \frac{i}{24}\right\} . \quad \text{(vi.)}$$

whence for a 6-inch layer—

$$A^1 = \text{Diff.} \times \left(\frac{n}{2} + \cdot 125\right) . \quad \text{(vii.)}$$

The total area (A^2) of this half-foot layer being thus—

$$A^2 = \tfrac{1}{2}b + A^1 \quad . \quad . \quad . \quad . \quad \text{(viii.)}$$

For a 3-inch layer—

$$A^1 = \text{Diff.} \times \left(\frac{n}{4} + \cdot 03125\right) \quad . \quad \text{(ix.)}$$

and for a 9-inch layer—

$$A^1 = \text{Diff.} \times \left(\frac{3n}{4} + \cdot 28125\right) \quad . \quad \text{(x.)}$$

CHAPTER III

APPLICATION OF THE TABLES

THE Tables and connected formulæ can, in the first place, be used for ascertaining the area of the cross-section of a bank or of a cut when the cross slope is level and d is known to the nearest inch.

Take the case of a bank 12 ft. high with a top width of 20 ft. and side slopes of $1\frac{1}{2}$ to 1 on both sides.

Then $S + S' = 1\frac{1}{2} + 1\frac{1}{2} = 3$, and the area of the cross-section of the bank will be, as $d = 12$ ft. and $b = 20$ ft.—

Area of central portion $b \times d$ $= 20 \times 12$	$= 240$ sq. ft.
End areas combined for $d = 12$ from Tables	$= 216$,,
Or the total area of the bank (A) will	$= 456$,,

For such a bank 12 ft. 6 in. high the area of the combined end areas of the lowest 6 in. would from equation (vii.) as Diff. = 3, be—

$$A^1 = 3(\tfrac{12}{2} + \cdot 125) = 18\cdot 375 \text{ sq. ft.}$$

and the area of the entire 6-in. layer—

$$A^2 = \tfrac{20}{2} + 18\cdot 375 = 28\cdot 375 \text{ sq. ft.}$$

the total area of the cross-section of the $12\tfrac{1}{2}$ ft. bank being thus—

$$A = 456 + 28\cdot 375 = 484\cdot 375 \text{ sq. ft.}$$

When the ground has a cross slope S″ to 1 as shown in Fig. I., Plate II., the area of bank needed could clearly be approximately ascertained from the Tables and formula (vi.) by calculating to the nearest inch the values of d' and d'' from the following formulæ—

$$d'(S'' - S) = \tfrac{1}{2}b + Sd \quad . \quad \text{(xi.)}$$

and

$$d''(S'' + S') = \tfrac{1}{2}b + S'd \quad . \quad \text{(xii.)}$$

The area of the cross-section can, however, be more easily ascertained (as the area of the triangle x is equal to that of the triangle y) by adding the area of the shaded portion in the lower left-hand corner of Fig. I. to the area of a bank on level

PLATE II

BANKS AND CUTTINGS ON CROSS SLOPES

FIG. I

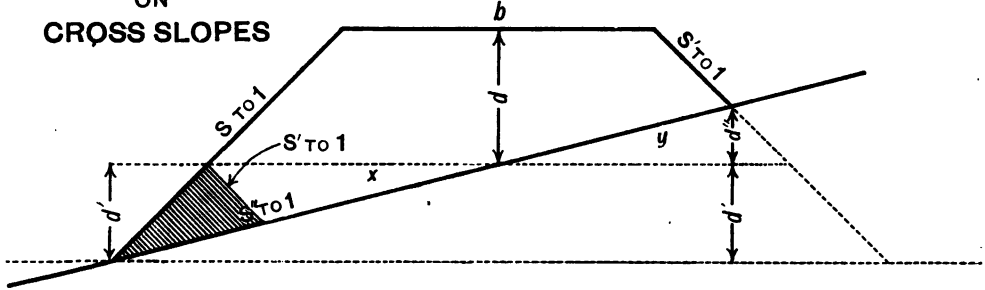
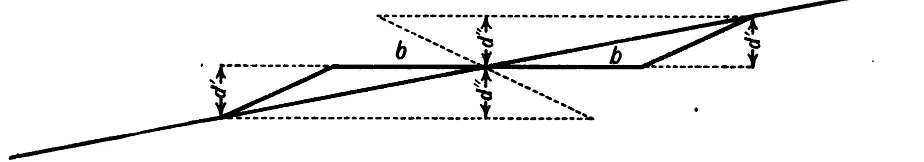


FIG. II



ground. This shaded area can be accurately calculated from the following formula—

$$A^3 = \tfrac{1}{2}d'^2\left\{(S + S') - \frac{(S + S')^2}{S'' + S'}\right\} \quad . \text{(xiii.)}$$

which reduces, when as is usually the case $S' = S$, to

$$A^4 = d'^2\left(S - \frac{2S^2}{S'' + S}\right) \quad . \quad . \quad \text{(xiv.)}$$

For the 12-ft. bank above considered, if the cross slope S'' to $1 = 4$ to 1, we have from formula (xi.)—

$$d'(4 - 1\tfrac{1}{2}) = \tfrac{1}{2} \times 20 + 1\tfrac{1}{2} \times 12$$

whence $d' = 11{\cdot}2$ ft.

therefore from formula (xiv.)—

$$A^4 = 11{\cdot}2^2\left\{1\tfrac{1}{2} - \frac{2 \times (\frac{3}{2})^2}{4 + 1\frac{1}{2}}\right\} = 125{\cdot}44 \times {\cdot}68 = 85{\cdot}3 \text{ sq. ft.}$$

and the area of the whole bank will be

$$A + A^4 = 456 + 85{\cdot}3 = 541{\cdot}3 \text{ sq. ft.}$$

which careful calculation will show is the correct area.

We thus have an easy and accurate method

of determining the cross-sectional area of a bank or of a cutting (a cutting being merely a bank turned upside down) on a cross slope, *whatever this cross slope may be.*

When such areas are equally partly in bank and partly in cutting, as shown in Fig. II., Plate II., and the slide slopes are similar

$$d'(S'' - S \text{ or } S') = b \quad . \quad \text{(xv.)}$$

also

$$A^5 = \frac{b^2}{2(S'' - S \text{ or } S')} \quad . \quad \text{(xvi.)}$$

Thus with $b = 10$, $S = 2$, and $S'' = 4$—

$$A^5 = \frac{10^2}{2(4-2)} = \frac{100}{4} = 25 \text{ sq. ft.}$$

When the areas are not equal, or the side slopes are dissimilar as illustrated in Plate II.*a*, the area of cutting in such case will similarly be

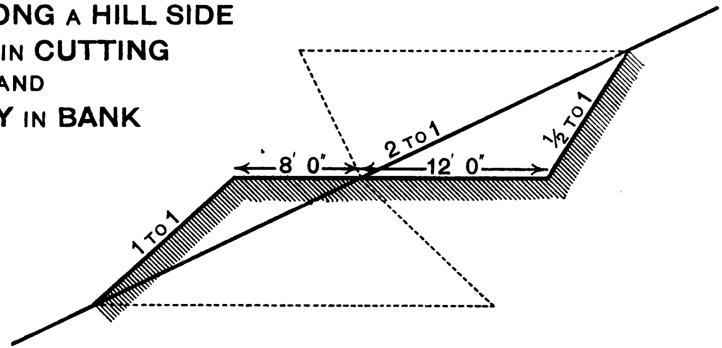
$$A^5 = \frac{12^2}{2(2 - \frac{1}{2})} = \frac{144}{3} = 48 \text{ sq. ft.}$$

and the area of embankment will be

$$A^5 = \frac{8^2}{2(2-1)} = \frac{64}{2} = 32 \text{ sq. ft.}$$

PLATE II.*a.*

CROSS SECTION OF A
20′ ROAD
CARRIED ALONG A HILL SIDE
PARTLY IN CUTTING
AND
PARTLY IN BANK



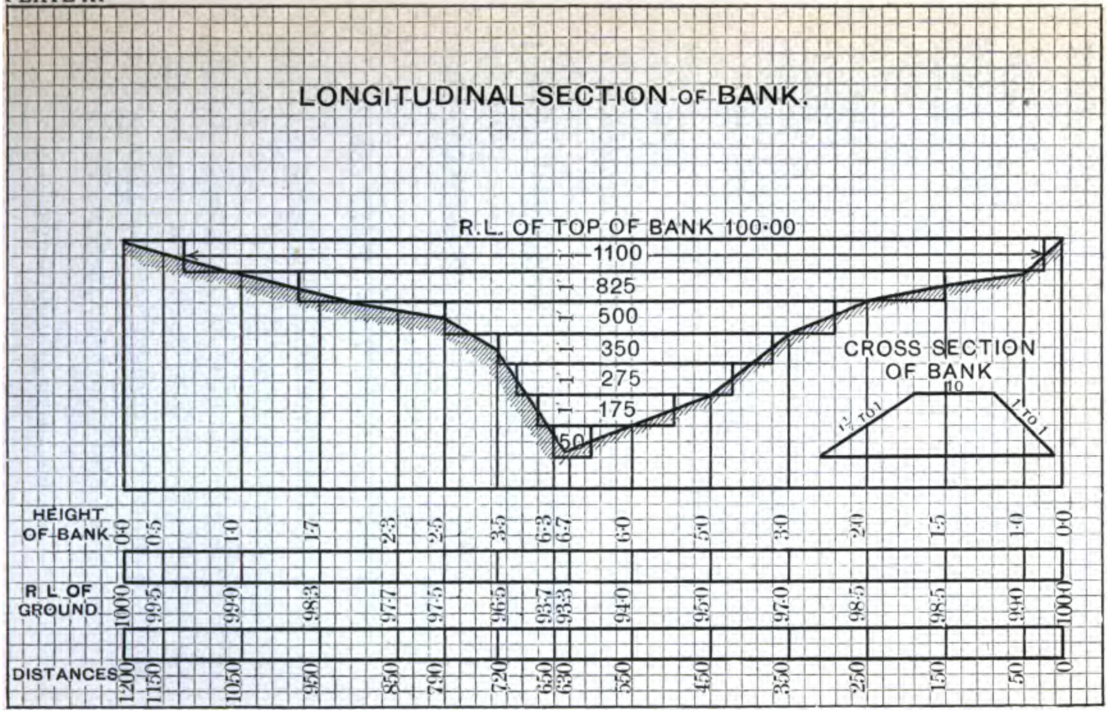
The correct cross-sectional areas of banks and cuttings having side slopes ordinarily used, can thus, without the preparation of cross sections, be quickly and accurately ascertained from the Tables and associated formulæ for both level ground and ground with a cross slope.

The Tables are, however, of special assistance in the calculation, by the method explained below, of the cubic contents of long lines of single or connected embankments and cuttings carried over or through ground which rises and falls to a considerable extent.

Consider Plate III. Here we have to ascertain the contents of a single bank with a top width of 10 ft. and side slopes of $1\frac{1}{2}$ to 1 on one side, and 1 to 1 on the other, carried, on the level, across a valley 1200 ft. wide, and having a maximum depth of 6·7 ft., or say 7 ft.

By drawing lines 1 ft. apart parallel to the formation level (top of bank), and ascertaining the length of each 1 ft. layer, the contents of the bank can be ascertained from the Tables, using the column for $S + S' = 1\frac{1}{2} + 1 = 2\frac{1}{2}$, in the following manner:—

PLATE III


LONGITUDINAL SECTION OF BANK.
R.L. OF TOP OF BANK 100·00
1100
825
500
350
275
175
50
CROSS SECTION OF BANK
10
$1\frac{1}{2}$ TO 1
1 TO 1
HEIGHT OF BANK
0·0 0·5 1·0 1·7 2·3 2·5 3·5 6·3 6·7 6·0 5·0 3·0 2·0 1·5 1·0 0·0
R.L. OF GROUND
100·0 99·5 99·0 98·3 97·7 97·5 96·5 93·7 93·3 94·0 95·0 97·0 98·5 98·5 99·0 100·0
DISTANCES
1200 1150 1050 950 850 790 720 650 630 550 450 350 250 150 50 0

Area of each 1 ft. layer in square feet.	Length of each 1 ft. layer in feet.	Contents of each 1 ft. layer in cubic feet.	Total contents at specified depths in cubic feet.
1st layer 10+ 1·25= 11·25	1100	12,375·00	12,375·00
2nd „ 10+ 3·75= 13·75	825	11,343·75	23,718·75
3rd „ 10+ 6·25= 16·25	500	8,125·00	31,843·75
4th „ 10+ 8·75= 18·75	350	6,562·50	38,406·25
5th „ 10+11·25= 21·25	275	5,843·75	44,250·00
6th „ 10+13·75= 23·75	175	4,156·25	48,406·25
7th „ 10+16·25= 26·25[1]	50	1,312·50	49,718·75
$A = 10 \times 7 + 61{\cdot}25 = 131{\cdot}25$			

Thus the total contents of the bank = 49,718·75 cub. ft.

If when the bank is being actually thrown up the completed portion is 3 ft. below formation level, the amount of earthwork put into the bank will clearly be

$$49{,}718{\cdot}75 - 31{,}843{\cdot}75 = 17{,}875 \text{ cub. ft.}$$

If the ground over which the bank is carried has a considerable cross slope, the quantity of earthwork needed will be increased, and the amount of such extra earthwork can be very approximately ascertained by calculating from formulæ (xi.) and (xiii.) the increase in the area

[1] For a 9-inch layer A^2 would = 21·33 sq. ft.

of the cross-section of the bank at its greatest depth, and then ascertaining a mean of this area for the entire bank in the manner illustrated in the following example.

Such mean area multiplied by the total length of the bank will very nearly give the quantity of the extra filling needed.

Thus if, in the case of the bank at present under consideration, the cross slope of the ground over which it is carried is 5 to 1 towards d', we have from formula (xi.)—

$$d'(5 - 1\tfrac{1}{2}) = \tfrac{1}{2} \times 10 + 1\tfrac{1}{2} \times 7$$

whence $$d' = 4{\cdot}43 \text{ ft.}$$

also from formula (xiii.)—

$$\begin{aligned} A^3 &= \tfrac{1}{2} \times 4{\cdot}43^2\left\{2\tfrac{1}{2} - \frac{(2\frac{1}{2})^2}{5+1}\right\} \\ &= 9{\cdot}8 \times 1{\cdot}46 \\ &= 14{\cdot}3 \text{ sq. ft.} \end{aligned}$$

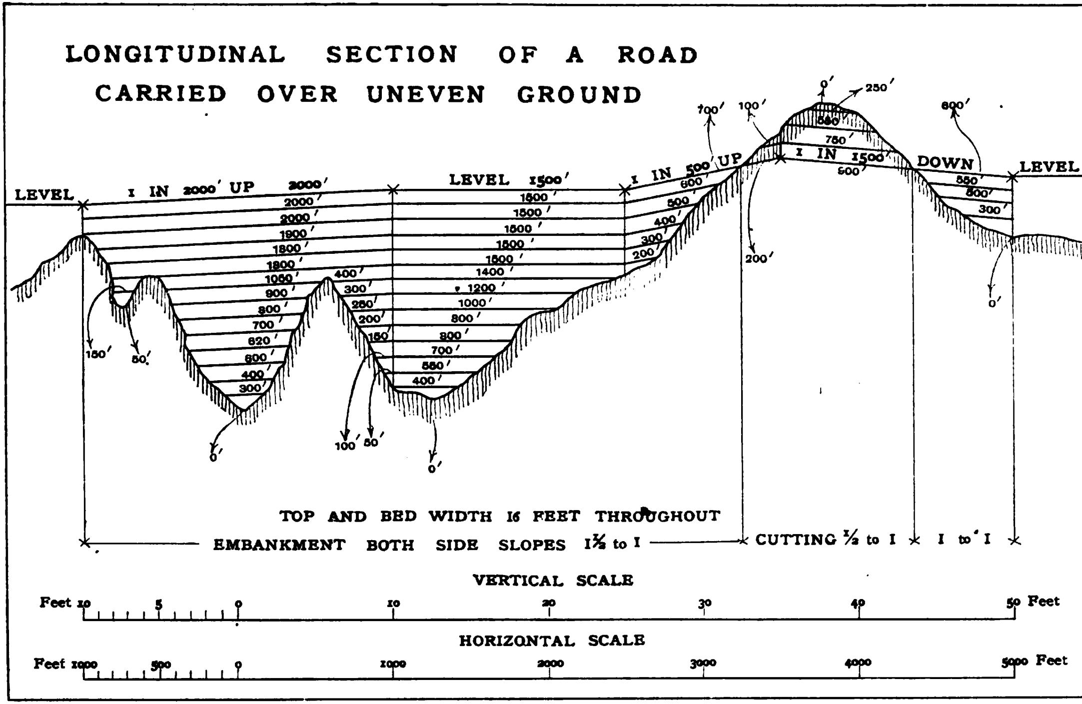
As the amount of earthwork in the bank with the cross slope level is 49,718·75 cub. ft. and the bank's length is 1200 ft., its mean area is $\dfrac{49{,}718{\cdot}75}{1200} = 41{\cdot}4$ sq. ft., or $\dfrac{41{\cdot}4}{131{\cdot}25}$

= 0·315 of the maximum area, the mean area for the additional earthwork will thus be say 14·3 × 0·315 = 4·50 sq. ft. Whence the amount of extra earthwork due to the bank being on a cross slope of 5 to 1, will be 4·50 × 1200 = 5400 cub. ft. The total amount of filling needed for the entire bank being thus about 55,120 cub. ft.

The method above illustrated can be applied to the calculation of the quantities of earthwork in a long series of connected banks and cuttings carried over or through uneven ground as illustrated in Plate IV.; the longer such a series of connected banks and cuttings, the smaller the relative amount of work necessary to ascertain the amount of earthwork required throughout.

The quantities of embankment and cutting needed under the conditions indicated on Plate IV. are worked out from the Tables and associated formulæ in the following statement, which gives, in a tabulated form, the contents of a connected series of banks and cuts having a total length of no less than 6000 ft.

PLATE IV



LONGITUDINAL SECTION OF A ROAD
CARRIED OVER UNEVEN GROUND
LEVEL
I IN 2000' UP
2000'
LEVEL 1500'
I IN 500' UP
I IN 1500'
DOWN
LEVEL
2000'
2000'
1900'
1800'
1800'
1050'
900'
800'
700'
620'
600'
400'
300'
400'
300'
250'
200'
150'
1500'
1500'
1500'
1500'
1500'
1400'
1200'
1000'
800'
800'
700'
550'
400'
600'
500'
400'
300'
200'
550'
750'
500'
550'
500'
300'
150'
50'
0'
100'
50'
0'
700'
100'
0'
250'
200'
600'
0'
TOP AND BED WIDTH 16 FEET THROUGHOUT
EMBANKMENT BOTH SIDE SLOPES 1½ to I
CUTTING ½ to I
I to I
VERTICAL SCALE
Feet 10 5 0 10 20 30 40 50 Feet
HORIZONTAL SCALE
Feet 1000 500 0 1000 2000 3000 4000 5000 Feet

Total length of upper surface of each 1 ft. layer.	Average length of each 1 ft. layer.	Area of cross-section of each 1 ft. layer.	Cubic contents of 1 ft. layers.	Total contents.
I. *Main embankment*		(S+S′=3) sq.ft.		
1st 4200 ft.	4150 ft.	16+ 1·5=17·5	72,625·0	72,625·0
2nd 4100 „	4050 „	16+ 4·5=20·5	83,025·0	155,650·0
3rd 4000 „	3900 „	16+ 7·5=23·5	91,650·0	247,300·0
4th 3800 „	3700 „	16+10·5=26·5	98,050·0	345,350·0
5th 3600 „	3550 „	16+13·5=29·5	104,725·0	450,075·0
6th 3500 „	3250 „	16+16·5=32·5	105,625·0	565,700·0
7th 3000 „	2725 „	16+19·5=35·5	96,737·5	662,437·5
8th 2450 „	2250 „	16+22·5=38·5	86,625·0	749,062·5
9th 2050 „	1875 „	16+25·5=41·5	77,812·5	826,875·0
10th 1700 „	1685 „	16+28·5=44·5	74,982·5	901,857·5
11th 1670 „	1535 „	16+31·5=47·5	72,912·5	974,770·0
12th 1400 „	1200 „	16+34·5=50·5	60,600·0	1,035,370·0
13th 1000 „	850 „	16+37·5=53·5	45,475·0	1,080,845·0
14th 700 „	350 „	16+40 5=56·5	19,775·0	1,100,620·0
	A = 16 × 14 + 294 = 518·0		1,100,620·0	
II. *Cutting* (S + S′ = 1)—				
1st 1100 ft.	975 ft.	16+0·50=16·5	16,087·5	16,087·5
2nd 850 „	700 „	16+1·50=17·5	12,250·0	28,337·5
3rd 550 „	400 „	16+2·50=18·5	7,400·0	35,737·5
4th 250 „	125 „	16+3·50=19·5	2,437·5	38,175·0
	A = 16 × 4 + 8 = 72·0		38,175·0	
			1,138,795·0	
III. *Second embankment* (S + S′ = 2)—				
1st 600 ft.	575 ft.	16+1=17	9,775	9,775
2nd 550 „	525 „	16+3=19	9,975	19,750
3rd 500 „	400 „	16+5=21	8,400	28,150
4th 300 „	150 „	16+7=23	3,450	31,600
	A = 16 × 4 + 16 = 80		31,600	
	Total amount of earthwork . .		1,170,395 cub. ft.	

To obtain the same result in the ordinary way would, with the stations at which cross-sections would be needed 100 ft. apart, have necessitated levels being taken for the preparation of cross-sections at no less than 60 stations, the calculation of the areas of the bank and cutting needed at each station, and finally the calculation from the areas so ascertained of the cubic contents of the banks and cutting by the prismoidal formula or other similar process.

In the above calculations the cross slope of the ground has been assumed to be negligible. Suppose, however, that it cannot be ignored, and is for the main bank 10 to 1. Then, as the greatest depth of the bank is 14 ft., we have from formula (xi.)—

$$d'(10 - 1\tfrac{1}{2}) = \tfrac{1}{2} \times 16 + 1\tfrac{1}{2} \times 14$$

and therefore $d' = 3{\cdot}4$ ft.

Also from formula (xiv.)—

$$A^4 = 3{\cdot}4^2\left(1\tfrac{1}{2} - \frac{2 \times \frac{9}{4}}{10 + 1\frac{1}{2}}\right)$$

$$= 11{\cdot}56 \times 1{\cdot}1 = 12{\cdot}716 \text{ sq. ft.}$$

Now as the contents of the bank are 1,100,620

cub. ft., and its length 4200 ft., its mean area is thus about 262 sq. ft., or $\frac{262}{518}$ = say ·51 of the maximum cross-section of the bank. The mean area of the increase in earthwork will thus be $12{\cdot}716 \times {\cdot}51 = 6{\cdot}485$ sq. ft., and the amount of extra earthwork needed due to the bank being carried over ground with a cross slope of 10 to 1, say $6{\cdot}5 \times 4200 = 27{,}300$ cub. ft., or an increase of only 0·025 of the total contents of the bank with the cross slope of the ground level. Unless, therefore, the cross slope is excessive, it need not generally be taken into consideration.

With the longitudinal section plotted to a scale of 100 ft. to the inch instead of 1000 ft. (approximately), the mean lengths of each 1 ft. layer could be more exactly ascertained than is the case in the above example, and the required amount of earthwork more accurately calculated.

It will, therefore, it is hoped, be clear that, by the method above outlined, the contents of the embankment and cutting required for a drain, canal, dam, road or railway can be easily and accurately ascertained by practically one set of calculations, whatever the length of either may be.

Table giving the End Areas in Square Feet of Bank and Cut Sections for their Side Slopes S and S′ to 1 added together.

Depth of bank or cut in ft.	S + S′ = 1		S + S′ = 1½		S + S′ = 2		S + S′ = 2½	
	For h=1 Diff.=1	For total depth.	For h=1 Diff. =1·5	For total depth.	For h=1 Diff. = 2	For total depth.	For h=1 Diff. =2·5	For total depth.
	area.	area.	area.	area.	area.	area.	area.	area.
1	0·5	0·5	0·75	0·75	1	1	1·25	1·25
2	1·5	2·0	2·25	3·00	3	4	3·75	5·00
3	2·5	4·5	3·75	6·75	5	9	6·25	11·25
4	3·5	8·0	5·25	12·00	7	16	8·75	20·00
5	4·5	12·5	6·75	18·75	9	25	11·25	31·25
6	5·5	18·0	8·25	27·00	11	36	13·75	45·00
7	6·5	24·5	9·75	36·75	13	49	16·25	61·25
8	7·5	32·0	11·25	48·00	15	64	18·75	80·00
9	8·5	40·5	12·75	60·75	17	81	21·25	101·25
10	9·5	50·0	14·25	75·00	19	100	23·75	125·00
11	10·5	60·5	15·75	90·75	21	121	26·25	151·25
12	11·5	72·0	17·25	108·00	23	144	28·75	180·00
13	12·5	84·5	18·75	126·75	25	169	31·25	211·25
14	13·5	98·0	20·25	147·00	27	196	33·75	245·00
15	14·5	112·5	21·75	168·75	29	225	36·25	281·25
16	15·5	128·0	23·25	192·00	31	256	38·75	320·00
17	16·5	144·5	24·75	216·75	33	289	41·25	361·25
18	17·5	162·0	26·25	243·00	35	324	43·75	405·00
19	18·5	180·5	27·75	270·75	37	361	46·25	437·25
20	19·5	200·0	29·25	300·00	39	400	48·75	500·00
21	20·5	220·5	30·75	330·75	41	441	51·25	551·25
22	21·5	242·0	32·25	363·00	43	484	53·75	605·00
23	22·5	264·5	33·75	396·75	45	529	56·25	661·25
24	23·5	288·0	35·25	432·00	47	576	58·75	720·00
25	24·5	312·5	36·75	468·75	49	625	61·25	781·25
26	25·5	338·0	38·25	507·00	51	676	63·75	845·00
27	26·5	364·5	39·75	546·75	53	729	66·25	911·25
28	27·5	392·0	41·25	588·00	55	784	68·75	980·00
29	28·5	420·5	42·75	630·75	57	841	71·25	1051·25
30	29·5	450·0	44·25	675·00	59	900	73·75	1125·00

TABLE GIVING THE END AREAS IN SQUARE FEET OF BANK AND CUT SECTIONS FOR THEIR SIDE SLOPES S AND S′ TO 1 ADDED TOGETHER.

Depth of bank or cut in ft.	$S + S' = 3$		$S + S' = 3\frac{1}{2}$		$S + S' = 4$		$S + S' = 4\frac{1}{2}$	
	For h=1 Diff. =3	For total depth.	For h=1 Diff. =3·5	For total depth.	For h=1 Diff. =4	For total depth.	For h=1 Diff. =4·5	For total depth.
	area.	area.	area.	area.	area.	area.	area.	area.
1	1·5	1·5	1·75	1·75	2	2	2·25	2·25
2	4·5	6·0	5·25	7·00	6	8	6·75	9·00
3	7·5	13·5	8·75	15·75	10	18	11·25	20·25
4	10·5	24·0	12·25	28·00	14	32	15·75	36·00
5	13·5	37·5	15·75	43·75	18	50	20·25	56·25
6	16·5	54·0	19·25	63·00	22	72.	24·75	81·00
7	19·5	73·5	22·75	85·75	26	98	29·25	110·25
8	22·5	96·0	26·25	112·00	30	128	33·75	144·00
9	25·5	121·5	29·75	141·75	34	162	38·25	182·25
10	28·5	150·0	33·25	175·00	38	200	42·75	225·00
11	31·5	181·5	36·75	211·75	42	242	47·25	272·25
12	34·5	216·0	40·25	252·00	46	288	51 75	324·00
13	37·5	253·5	43·75	295·75	50	338	56·25	380·25
14	40·5	294·0	47·25	343·00	54	392	60·75	441·00
15	43·5	337·5	50·75	393·75	58	450	65·25	506·25
16	46·5	384·0	54·25	448·00	62	512	69·75	576·00
17	49·5	433·5	57·75	505·75	66	578	74·25	650·25
18	52·5	486·0	61·25	567·00	70	648	78·75	729·00
19	55·5	541·5	64·75	631·75	74	722	83·25	812·25
20	58·5	600·0	68·25	700·00	78	800	87·75	900·00
21	61·5	661·5	71·75	771·75	82	882	92·25	992·25
22	64·5	726·0	75·25	847·00	86	968	96·75	1089·00
23	67·5	793·5	78·75	925·75	90	1058	101·25	1190·25
24	70·5	864·0	82·25	1008·00	94	1152	105·75	1296·00
25	73·5	937·5	85·75	1093·75	98	1250	110·25	1406·25
26	76·5	1014·0	89·25	1183·00	102	1352	114·75	1521·00
27	79·5	1093·5	92·75	1275·75	106	1458	119·25	1640·25
28	82·5	1176·0	96·25	1372·00	110	1568	123·75	1764·00
29	85·5	1261·5	99·75	1471·75	114	1682	128·25	1892·25
30	88·5	1350·0	103·25	1575·00	118	1800	132·75	2025·00

TABLE GIVING THE END AREAS IN SQUARE FEET OF BANK AND CUT SECTIONS FOR THEIR SIDE SLOPES S AND S TO 1 ADDED TOGETHER.

Depth of bank or cut in ft.	S + S′ = 5		S + S′ = 6		S + S′ = 7		S + S′ = 8	
	For h=1 Diff. =5	For total depth.	For h=1 Diff. =6	For total depth.	For h=1 Diff. =7	For total depth.	For h=1 Diff. =8	For total depth.
	area.	area.	area.	area.	area.	area.	area.	area.
1	2·5	2·5	3	3	3·5	3·5	4	4
2	7·5	10·0	9	12	10·5	14·0	12	16
3	12·5	22·5	15	27	17·5	31·5	20	36
4	17·5	40·0	21	48	24·5	56·0	28	64
5	22·5	62·5	27	75	31·5	87·5	36	100
6	27·5	90·0	33	108	38·5	126·0	44	144
7	32·5	122·5	39	147	45·5	171·5	52	196
8	37·5	160·5	45	192	52·5	224·0	60	256
9	42·5	202·5	51	243	59·5	283·5	68	324
10	47·5	250·0	57	300	66·5	350·0	76	400
11	52·5	302·5	63	363	73·5	423·5	84	484
12	57·5	360·0	69	432	80·5	504·0	92	576
13	62·5	422·5	75	507	87·5	591·5	100	676
14	67·5	490·0	81	588	94·5	686·0	108	784
15	72·5	562·5	87	675	101·5	787·5	116	900
16	77·5	640·0	93	768	108·5	896·0	124	1024
17	82·5	722·5	99	867	115·5	1011·5	132	1156
18	87·5	810·0	105	972	122·5	1134·0	140	1296
19	92·5	902·5	111	1083	129·5	1263·5	148	1444
20	97·5	1000·0	117	1200	136·5	1400·0	156	1600
21	102·5	1102·5	123	1323	143·5	1543·5	164	1764
22	107·5	1210·0	129	1452	150·5	1694·0	172	1936
23	112·5	1322·5	135	1587	157·5	1851·5	180	2116
24	117·5	1440·0	141	1728	164·5	2016·0	188	2304
25	122·5	1562·5	147	1875	171·5	2187·5	196	2500
26	127·5	1690·0	153	2028	178·5	2366·0	204	2704
27	132·5	1822·5	159	2187	185·5	2551·5	212	2916
28	137·5	1960·0	165	2352	192·5	2744·0	220	3136
29	142·5	2102·5	171	2523	199·5	2943·5	228	3364
30	147·5	2250·0	177	2700	206·5	3150·0	236	3600

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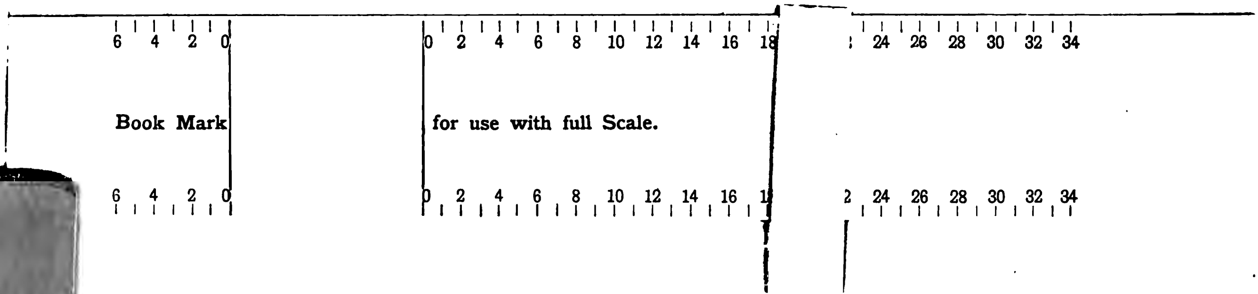
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